# NATIONAL AIR INTELLIGENCE CENTER

THE CONCEPT OF HETEROSYNCHRONOUS SHIP
BORNE DUAL BASE RADAR

by

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ABSTRACT   Through an analysis of domestic and foreign dual based radars which currently exist, this article puts forward a concept of using communications satellites to act as heterosynchonous signal sources associated with dual based radar and using pulse phase modulation technology to carry out dual base data transmission in order to realize ship borne dual based radar functions.   In conjunction with this, it carries out a simple analysis with regard to radar measurements and precisions realized by the method in question, making explanations in respect to all component technologies.

Tactical dual based radar systems are one type of new radar system. It was developed in order to adapt to the needs of the modern battlefield's complicated electronic environment as well as added electronic warfare capabilities. Compared to current single base radar systems, dual based radars possess a good number of unique advantages: (1) combat troops carrying receivers--in cases where observational capabilities are not weak--can maintain electromagnetic silence, strengthening the cover of combat troops; (2) under conditions of electronic counter measures currently available, the concealment characteristics of receivers can make it difficult for the enemy to determine the direction of jamming; (3) they are capable of effectively observing concealed combat platforms of single base radar systems which are difficult to observe; (4) they are capable of lowering the destructive effectiveness of antiradiation missiles.

Beginning in the 1970's, such nations as the U.S., U.K., and so on, had already put in large numbers of personnel and amounts of materiel in order to carry out large amounts of research and experimental work, making dual base radar development reach a considerable level. China began research with regard to dual based radar relatively late. The starting point was comparatively low. If there is not a speeding up, it will be difficult to overtake the pace of world radar development. In the future, it would be difficult to be in an invincible position on the high technology battlefield. This article attempts--based on current technology-- to propose, through the presentation of a concept with regard to ship borne dual based radar acting as a brick to attract jade, that those possessing the same knowledge will take research on dual based radar in China's military forces and push it to a new level.

I. Current Status of Dual Based Radar Development Inside and Outside China

In structural terms, dual based radar systems are much more complicated than single base radars. Speaking with regard to a model of dual based radar system with the most basic functions, it is necessary to solve the 3 key problems below:

I. Coordinating synchronicity between receivers and transmiters, that is, time synchronicity and transmiter and receiver beam directional synchronicity aimed at searching out targets or air sectors.

II. Precisely specifying in real time the relative locations of transmiters and receivers.

III. Carrying out in real time dual base signal processing.

At the present time, with respect to solution methods for these problems, it is basically possible to induce the following several classes below.

1. Coordinated Reception and Transmission Synchronicity

(1) Space Synchronicity

a. Reception and Transmission Beams Carry Out Synchronous

Scanning in Accordance with Predetermined Programs
    As far as opting for the use of this type of method is
concerned, it is only capable of searching out targets on
predetermined isometric ellipsoid surfaces. With respect to
completing searches for and simultaneously tracking moving targets
which have already been discovered, an information transmission
channel is needed in order to adjust reception beam directions in
real time.
    b.  Pulse Pursuit Methods
    This is making use of receiver beams to go pursue the spacial
locations associated with transmited pulses each instant. Opting
for the use of this type of method requires high speed computers
and high precision, high stability phase control array antennas in
order to suppor⁺ it. At the same time, it requires inf.rmation
transmission channels in order to be assured.
    c.  Multiple Beam Coverage
    (a)  Reception antennas opt for the use of fixed multiple
beams. Multiple beams are composed of antenna main beams and their
grid lobes. In order to lower multiple beam antenna costs,  /74
the number of receiver channels is equal to the number of main
lobes. In order to eliminate azimuth fuzziness given rise to by
grid lobes, a distance wave gate is set in each channel. Opting
for the use of this type of method, target azimuth precision bases
are low.
    (b)  Floodlight irradiation transmissions and narrow beam
scanning reception. Opting for the use of this type of method,
target loss rates are relatively high.
    (c)  Floodlight irradiation transmissions and multiple beam
reception. This is capable of lowering loss rates. However, it
can easily produce azimuth fuzziness or lower azimuth precision.
    (2)  Time Synchronicity
    a.  As far as transmission of time synchronous information by
data link methods is concerned, a data link is set up between
reception bases, directly transfering such information as
transmission pulse start moments, positions, and so on. This type
of method requires that both sending and receiving bases must
possess high stability clocks--for example, atomic clocks, and so
on. Moreover, information transfers are subject to limitations
associated with the data links they make use of.
    b.  Using transmiter direct link detection pulses to act as
receiver time synchronicity signals. The method in question is
subject to line of sight influences. Moreover, target scattering
echoes can easily produce confused receiver operation, used in
cases where transmiting bases are space platforms.
    2.  Transmiter Position Signal Transfer
    (1)  In dual base radar testing phases, transmiter locations
are fixed or flight plans are strictly implemented. In this way,
receivers are capable, during data processing, of knowing before
the fact the locations of transmiters. There is no need for
information transfer loops. However, as far as this type of method
is concerned, it is difficult to satisfy the requirements of actual
combat.

3

(2)  Transmiter Locations and Data Link Real Time Transmissions

3.  Dual Base Signals and Data Processing

With respect to dual base signals and data processing, at the present time, universal option is made for the use of specialized processing equipment as well as high speed computers in order to support them.  However, in regard to requirements associated with specialized processing and computer systems and dual base operating methods for the use of which option is made, there are strong relationships.

## II.  Characteristics of Satellite Heterosynchronous Ship Borne Dual Base Radar as well as a General Idea of Search and Positioning

The ship borne dual base radar which this article puts forward and the dual based radar which is realized at the present time inside and outside China through the various types of technologies above are not the same.  Due to the fact that the periods of development and test manufacture of these radars were relatively early, certain systems and technologies which appeared after them have still not yet functioned as foreseen at that time.  In conjunction with this, additional consideration is given.  Thus, in the resolution of cooperation between bases and data achieving transfer and processing, considerable time, energy, and financial strength have been spent.  In conjunction with this, technologies in dual base testing processes are made to guarantee meeting numerous difficulties.  Before moving toward mature independent systems, there is a high degree of dependence on cutting edge science and technology and cost benefit ratios staying high.

We believe that, under today's conditions of the universal utilization of synchronous communications satellites and global positioning and navigation systems, in a present where the development of microwave technology and devices has already taken a great leap forward, to solve cooperation between dual base radar system bases as well as information data acquisition, transfer, processing, and so on, there is no need to again opt for the use of expensive and technically difficult methods such as atomic clocks, data links, and so on.  However, using currently existing specialized synchronous satellite transmission pulse signals or directly making use of television field synchronous signals to carry out changes--by making use of the common collection of receiving bases--in the solving of problems associated with directional synchronicity and the transfer of transmiter platform positions, it is possible to opt for the use of the carrying out of phase encryption modulation with regard to detection pulses, taking true direction data associated with transmiter acicular detection beams as well as transmiter platform position data and modulating it into detection pulse series.  There is omnidirectional reception within beam angle ranges by wide angle receivers.  At the same time that receivers pick up target scattering echo signal time delays, transmiter platform position data and detection beam true direction data are demodulated.  Within receivers--through data processing

4

systems--calculations are done to determine target space locations.

In this way, so long as requirements made on transmiters and receivers are appropriate, it is then possible to realize the basic functions of dual base radar systems.

Requirements with regard to transmiters are:

1. There be satellite heterosynchronous signal reception systems;

2. There be GPS composite navigation systems;

3. They possess phase control array beam scanning and detection capabilities;

4. They possess systems for the extraction and encryption of data with regard to the positions of the bases in question and the directior of scanning and detection beams;

5. They possess capbilities to carry out phase encryption, modulation, and transmission with regard to transmission pulses./75

Requirements with regard to receivers are:

1. There be satellite heterosynchronous signal reception systems;

2. There be GPS composite navigation systems;

3. They possess wide angle, high gain reception capabilities;

4. There be direct link or scattering echo pulse series phase decryption systems;

5. There be data processing systems.

General Idea of Search and Target Position Point Determination:

As far as transmission bases are concerned, with continuous triggering of synchronous communications satellite heterosynchronous pulses, it is possible, with regard to appearances of the enemy in sea and air sectors, to carry out scanning and detection. The scanning and detection beams are composed of pulse series carrying signals associated with transmission base locations as well as true beam direction data. At the same time each pulse is sent out, part of energies are broken down to make another omnidirectional transmission used to provide data reception for receivers in line of sight.

Receivers in line of sight are capable--in real time--of receiving data signals sent out by transmiters to obtain transmiter position and beam direction information. Due to coordination of synchronous pulses received by synchronous satellites--after receiving target scattering echoes--it is possible to obtain equations of time associated with various detection pulses propogated out into space. From equations of time associated with transmiting base positions, GPS positions of receivers themselves, as well as pulses propogated out into space, it is possible to obtain a target isometric rotation ellipsoid surface with two bases as foci. The intersection points associated with the isometric rotation ellipsoid surface in question and transmission beam directions are the location points of targets in space. With regard to transmission of data associated with receivers outside of
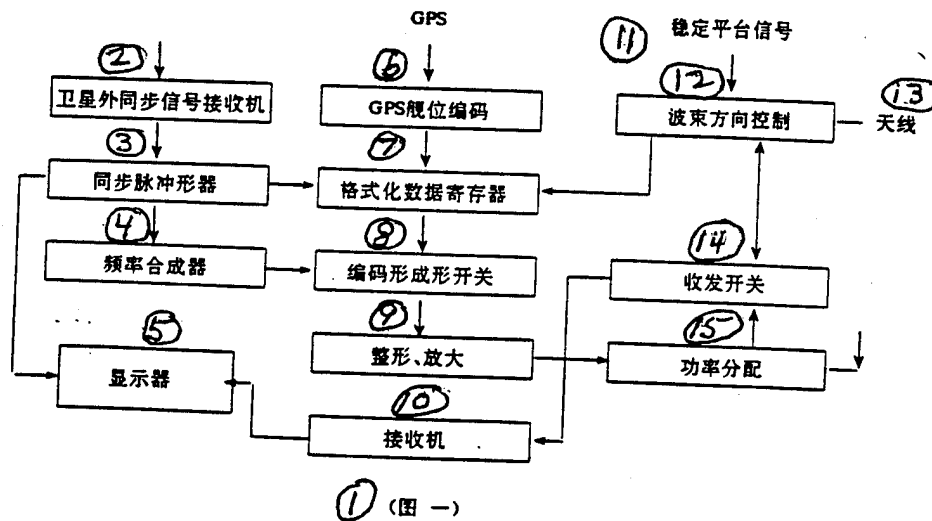
line of sight, it is possible--from echo pulse series--to demodulate and obtain them. However, as far as data transfered at this time is concerned--when multiple targets are met with and resolution is difficult--data reliability will drop.

III. Operational Processes Associated with Satellite Heterosynchronous Ship Borne Dual Base Radar

    (I) Line and Block Chart of Principles
    1. Transmitters



GPS      稳定平台信号

| ② 卫星外同步信号接收机 | ⑥ GPS舰位编码 | ⑪ ⑫ 波束方向控制 | ⑬ 天线 |

③ 同步脉冲形器 → ⑦ 格式化数据寄存器

④ 频率合成器 → ⑧ 编码形成形开关    ⑭ 收发开关

⑤ 显示器    ⑨ 整形、放大    ⑮ 功率分配

⑩ 接收机

① (图 —)

(1) (Fig.I) (2) Satellite Heterosynchronous Signal Receiver (3) Synchronous Pulse Formation Device (4) Frequency Synthesizer (5) Display Device (6) GPS Navigational Positioning Encryption (7) Formated Data Register (8) Encryption Form Creation Switch (9) Full Form, Amplification (10) Receiver (11) Stable Platform Signal (12) Beam Direction Control (13) Antenna (14) Receive/Transmit Switch (15) Power Distribution

## 2. Receivers



(图二)
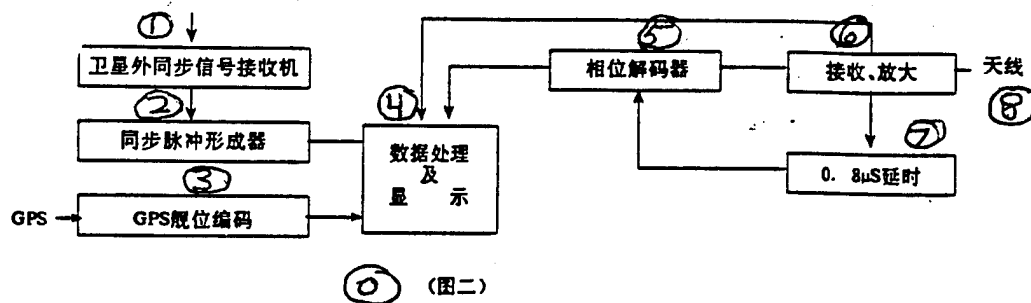
(0) Fig.II (1) Satellite Heterosynchronous Signal Receiver (2) Synchronous Pulse Formation Device (3) GPS Navigational Positioning Encryption (4) Data Processing and Display (5) Phase Decryption Device (6) Reception, Amplification (7) 0.8μS Delay (8) Antenna

(II) Operational Processes
1. Transmiters
Satellite heterosynchronous signals that receivers receive come from heterosynchronous signals associated with synchronous communications satellites. Synchronous pulses with repetition periods of 1ms go through heterosynchronous pulse formation device frequency multiplication, amplification, full forming, and formation, are sent to synchronous signal phase lock devices to lock on phase. Frequency synthesizers are controled by synchronous signal phase lock devices to form needed microwave frequencies to act as transmiter microwave frequency sources.

As far as accurate navigational positioning signals provided to GPS composite navigation system transmiters are concerned, GPS navigational positions are gathered from transmiters and collected in encryption formation devices--in conjunction with this, forming encrypted code. When heterosynchonous signal pulses are triggered, navigation position signal data in formated data registers is taken and refurbished.

Transmiter beam direction information comes from data transmission terminals associated with search beam direction control devices. Each time directions make a jump, direction data bits are refurbished with respect to formated data in registers.
Data in formated data registers is cycled out.
Synthesized frequencies and output data go through phase encryption formation switches, turning into phase modulated pulses.

Going through full forming and power amplification, they are sent

to power distribution devices to carry out power distribution. Most energy components go through receive/transmit switches and are sent to phase control array antennas to be sent out, acting as detection pulses. On another circuit, small parts of energies are sent to omnidirectional antennas to be sent out, acting as data transmissions.

In order to make transmiting ships not lose observation capabilities, it is possible to install receivers on transmiting ships to make them possess single base radar capabilities.

2. Receivers

Synchronous signal acquisition is the same as transmiters.

Receivers opt for the use of multiple channel wide angle reception. In this, one channel is divided out to act as omnidirectional reception, used in collecting information send out by receivers in line of sight.

Receivers take direct link pulse information associated with transmiters in line of sight or scattering echo pulse information associated with transmiters outside line of sight and make reception going through omnidirectional or wide angle reception antennas. After going through amplification, the data is sent into phase modulation decryption devices to demodulate the data sent out by transmiters. Data is sent to buffers and awaits use in data processing.

Receiver navigational position data is supplied by GPS composite navigation systems.

The delay time $\Delta T$ associated with echo pulses of each target are gotten comparing synchronous signal pulse triggering times and times received by target scattering echoes.

After the obtaining of ship position information associated with transmiting ships, transmission beam irradiation direction information, as well as target scattering echo delay times, it is then possible to calculate out relative positions of targets in space.


IV. Positioning Calculations and Precision Analyses

(I)  Equations of Time Associated with Receiving and Transmiting Base Heterosynchronous Pulse Signals.                    /77
Due to the fact that synchronous pulses associated with receiving and transmiting bases are, in all cases, the same heterosynchronous signal coming through receivers from the same stationary satellite and obtained through the same frequency multiplication, it is only due to their position on the earth's surface being different that the times of arrival of the same heterosynchronous pulse are different. Also for this reason equations of time are produced because of differences in the distances of the two bases to synchronous satellites. The size of this difference value--after receivers obtain transmiter position data--can be obtained through calculations by the methods below.
Assuming that geocoordinates of receiving and transmiting bases are, respectively, $(\lambda r, \Phi r, Hr)$ , $(\lambda t, \Phi t, Ht)$, the point position

of synchronous satellites is ($\lambda s, \Phi s, Hs$).

Setting up a georectangular coordinate system, the global parameters selected for use are Kelasuofusiji (phonetic) ellipsoidal parameters: $a=6378245m$, $e2=0.006693422$. Then, the coordinates of receiver (R), transmitter (T), and synchronous satellite (S) in the georectangular coordinate system are, respectively, ($Xi, Yi, Zi$); ($i: r, t, s$).

$$X_i = \left[ \frac{a}{(1-e^2\sin^2\Phi_i)^{0.5}} + H_i \right] \cos\varphi_i \cdot \cos\lambda_i$$

$$Y_i = \left[ \frac{a}{(1-e^2\sin^2\Phi_i)^{0.5}} + H_i \right] \cos\varphi_i \cdot \sin\lambda_i$$

$$Z_i = \left[ \frac{a}{(1-e^2\sin^2\Phi_i)^{0.5}} \cdot (1-e^2) + H_i \right] \sin\varphi_i$$

As a result, the difference in paths of satellite synchronous pulses to the two receiving and transmiting bases is:

$\Delta s = SR-ST$

$= [(Xs - Xr)2 + (Ys - Yr)2 + (Zs - Zr)2]0.5 - [(Xs - Xt)2 + (Ys - Yt)2 + (Zs - Zt)2]0.5$

Equations of time associated with each pair of corresponding synchronous pulses given rise to by path differences between receiving and transmiting bases are:

$$\Delta t = \frac{\Delta_s}{C}$$

(II) Target Position Calculations
1. Coordinate System Establishment
For the sake of simple and convenient data processing, it is possible to set up rectangular coordinate systems using receiver platforms as origin point and geotangential planes past receiver platforms as the plane XOY. As on maps, the OX direction is the direction of true north. The OY axis and OZ axis are determined in accordance with the left hand spiral law. Then, the position of the receiver antenna in the coordinate system in question is:
Xr = 0, Yr = 0, Zr = Hr
2. Location of Transmiter Antennas in the Coordinate System in Question

9

$$X_t = (q_i - q_r) \cdot [1852.2 - 9.3\cos(q_r + q_t)]$$

$$T_t = -(\lambda_i - \lambda_r) \cdot \frac{a}{(1 - e^2\sin^2 q_r)^{0.5}} \cdot \cos(\frac{q_r + q_t}{2}/60 \times 57.3)$$

$$Z_t = -\frac{X_t^2 + Y_t^2}{2R} + H_t$$

3. Assuming that the coordinates of targets in the coordinate system in question are (Xm,Ym,Zm), the time delay associated with receivers receiving target scattering echoes is ΔT.

The target distribution isometric rotational ellipsoid surface is:

$$[(X_m - X_t)^2 + (Y_m - Y_t)^2 + (Z_m - Z_t)_2]^{0.5} + [(X_m - X_r)^2 + (Y_m - Y_r)^2 + (Z_m - Z_r)^2]^{0.5} = \Delta T \cdot C + \Delta \quad (1)$$

4. Assuming that transmiter real time detection direction is azimuth B, angle of elevation α, then, the directional cosine associated with the transmiter beam direction in the xyz-O coordinate system is:

cosα • cos(360°-B)i + cosα • sin(360°-B)j + sinα.k

5. The detection beam ray equation past the transmiter antenna point (Xt,Yt,Zt) is:

$$\frac{X_m - X_t}{\cos\alpha \cdot \cos(360° - B)} = \frac{Y_m - Y_t}{\cos\alpha \cdot \sin(360° - B)} = \frac{Z_m - Z_t}{\sin\alpha} \quad . \quad (2)$$

6. Solving equation sets (1) and (2), it is then possible to obtain target position coordinates. From these coordinate values, it is then possible to obtain the three nominal values of azimuth, distance, and angle of elevation associated with targets relative to reception and transmission bases.

(III) Analysis of Principles and Precision

Opting for the use of satellite heterosynchronous methods to realize dual base radar functions, the factors influencing the precision of target determination are primarily the several ones below.

1. Reception Base Position Precisions Supplied by GPS

At the present time, as far as GPS receivers opting for the use of C/A code is concerned, base determining precisions are capable, in all cases, of being controled within 75 meters. If option is made for the use of difference technologies and option is made for the use of GPS composite navigation systems, then positioning accuracies will be even higher.

The precision of positions for receiving and transmiting bases

supplied by GPS will influence the precision of receiving and transmiting synchronous equation of time corrections (Δt) as well as target calculation precisions.

As far as the former is concerned, due to the fact that--in middle and low latitude areas of the sea--ship position error directions and the direction of synchronous signal propogation paths approach the vertical, influences on synchronous time equation corrections, therefore, can be omited.

With regard to the influences of target calculation precisions--due to the fact that the distance of the two bases is far smaller than target detection ranges--target distribution rotational ellipsoid surfaces approach ellipsoid surfaces. Therefore, in terms of radial distances, there are produced, at the s me times and places, one order of magni ude errors.

2. Influences of Synchronous Satellite Positioning Location Errors as Well as Drift with Regard to Precisions of Synchronous Pulse Time Difference Corrections

Due to the fact that--as far as synchronous satellite positioning at altitudes 36000km distant from the surface of the earth is concerned--receiving and transmiting bases can basically be considered as the same point, the positioning errors and deviations given rise to by drift relative to the distances to receiving and transmiting bases are limited to only decimal points.

As a result, the errors in question can also be ignored.

3. Influences of Transmiter Beam Angles as Well as Their Jump Intervals on Target Position Determination Precision

This is a main factor influencing target positioning precisions. As far as analyses with respect to this type of error are concerned, it is possible to opt for the use of analogous methods to obtain them. Normally, receiving and transmiting base dispositions are not advised to exceed 30 nautical miles. With regard to targets placed at 150-200 kilometer locations, target isometric ellipsoid surfaces approach an ellipsoid surface. In the case of transmission beam angles, target positions obtained from the center of the sphere moving toward the surface of the sphere are basically the same in the size of scattering errors in various directions. They are $0.5\theta \cdot R_m$, $\theta$: beam angle. $R_m$: target range. As a result, target position accuracies measured by the dual bases in question and single bases should be the same order of magnitude.

4. The Influences of Electromagnetic Wave Propagation Speed Fluctuations

Receiving and transmiting heterosynchronous pulse propogation paths are basically consistent with each other. Electromagnetic wave propagation speed fluctuations--speaking in terms of receiving and transmiting bases--tend toward consistency. The influences on Δ are tiny to the point of not needing consideration.

5. Influences of Errors Produced in Coordinate Systems Set Up Using the Receiving Base as the Coordinate Origin Point and Directly Making Use of Transmission Beam Absolute Directions

Due to true transmission beam directions being azimuth angles

and angles of elevation at transmiting bases with a view toward true north and tangent planes, the data in question was directly used in receiver coordinate systems. The maximum direction errors in a certain specially designated direction can reach maximum values. The values in question are related to receiving and transmiting ranges as the nautical mile number associated with the two bases. If the distance of the two bases is 30 nautical miles, then, the maximum error value is 30'(0.5°). It is possible to satisfy positioning accuracy requirements.

## V. A Few Points of Explanation with Regard to Technical Realization

1. Enc ption Modulation
(1) Encryption Formats
The transmission data which transmiters must complete is data with a total of 18 digits--longitude 6 digits, latitude 6 digits, azimuth 4 digits, angle of elevation 2 digits. In addition, there are 4 digits of data discrimination code (longitude, latitude, azimuth, angle of elevation) for a total of 22 digits. During realization, it is possible to consider one pulse modulation /79 of 4 bits of 1 or 0 code as completing the modulation of one code group. Data associated with one pulse is capable of representing 16 different code groups. Among them, 10 are 0-9 digits. 4 are discrimiation codes. 2 are latitude + or - codes. The data format is:

| Longitude 经度 | | Latitude 纬度 | | Azimuth 方位 | | Angle of Elevation 仰角 | |
|---|---|---|---|---|---|---|---|
| 1010 | * * *   * * * | 1011 | * * *   * * * | 1100 | * * *   * * * | 1101 | * * *   * * * |

In this way, one complete data set only requires 22 pulse cycles, and it is then possible to completely transmit it.
(2) Modulation Methods:
With regard to each detection pulse ($1.6\mu S$), it is divided into 5 sections of phase modulation. The first section is the reference phase section. It accounts for $0.8\mu S$. The 4 sections after that are data digit sections. They each account for $0.2\mu S$. Their phase and the reference phase being the same is "1". Being opposite to the reference phase is "0". Each 4 bits of (0,1) data in transmiter data registers acts as a group in the triggering of pulses. In series, they are sent to encryption formation switches.

Phase modulation is carried out on frequencies supplied by frequency synthesizers.
2. Demodulation and Data Separation

12

Pulses being recieved are amplified in real time. One path is delayed 0.8μS and sent to phase demodulation devices. After the other path does not go through delay, half 0.8μS pulse phases are coherent. Data is demodulated, and the data is sent to decision units. When it is determined that the real time data is data discrimination code, corresponding data is opened up and sent through channels. After preparations for reception, the data sent in by several pulses arrives at phase data elements.

3. Data Rate Problems

Due to the fact that the radar systems in question are planned with set repetition cycles of 1ms, the repetition frequency is 1000 cycles. However, transmiters sending one complete datum only requires 22 pulse cycles. Therefore, each second, it is possible to repeat data transmission approximately 50 times. Speaking in terms of transmiters associated with data transmission out of line of sight and dependent on scattering echoes, in terms of basic principles, the scanning angular velocities, at a maximum, can reach $\theta \times 10^3 / 22$. $\theta$ is beam angle.